Department of Science, Information Technology, Innovation and the Arts

Eucalypt open-forests

Regrowth Benefits - Management Guideline

Great state. Great opportunity.

Queensland Government

Prepared by

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Cover image T. Ryan

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Summary

- Eucalypt open-forests occur over a large area of eastern Queensland, from the New South Wales border to Cape York Peninsula.
- Standing stocks of carbon in above-ground plant parts in Queensland's eucalypt open-forests range from about 25 to 250 tonnes of carbon per hectare, which translates to about 86 to 860 tonnes of carbon dioxide equivalent (tCO_2-e) per hectare.
- The estimated peak rate of carbon accumulation into living biomass during restoration of eucalypt open-forests ranges from 2 to 17 tCO_2-e per hectare per year.
- Rainfall and past clearing history have a large influence on restoration and carbon accumulation in eucalypt open-forests, but ongoing management can also have a large effect.
- Continuous high grazing pressure, clearing, and hot fires[1] will slow and may prevent the restoration of eucalypt open forests, as these will inhibit tree establishment and growth.
- Livestock grazing can be compatible with reforestation in eucalypt open-forests, as long as grazing pressure is held at low to moderate levels, and strategic spelling is adequate to allow tree recruitment. Increasing the biomass of trees will reduce the carrying capacity for grazing.
- Timber harvesting can be compatible with reforestation in eucalypt open-forests, although it will slow the rate of carbon accumulation and reduce carbon stocks in the short term.
- Regrowing eucalypt open-forests will benefit biodiversity, especially animals such as birds, reptiles and mammals that are strongly dependent upon eucalypt open-forests for habitat.

[1] In this guideline, the term 'hot fire' is equivalent to a moderate or high severity or higher. 'Hot fires' can occur whenever humidity and soil moisture levels are low, and they most commonly occur in the late dry season. In Queensland, this tends to be in spring or early summer. See the Department of National Parks, Recreation, Sport and Racing's bioregional planned burn guidelines for definitions of fire severity for Queensland open forests and woodlands http://www.nprsr.qld.gov.au/managing/planned-burn-guidelines.html .

Description

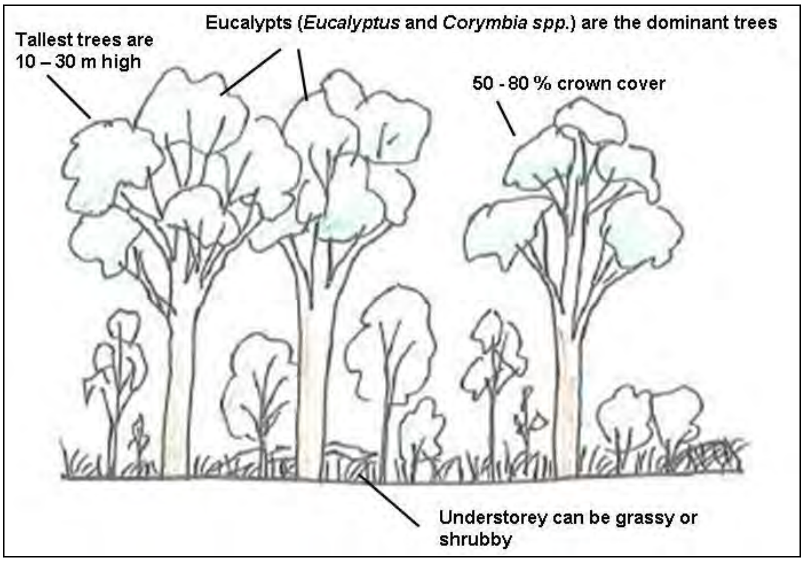


Figure 1: Structural diagram of eucalypt open-forest

Eucalypt open-forests are also known as dry sclerophyll forests. Generally, eucalypt open-forests in Queensland have the following features:

- Eucalypts[2] and sometimes *Angophora, Syncarpia* and *Lophostemon* spp. are the tallest trees, and form the upper canopy layer. They range in height from 10m to 30m.
- Canopy cover can vary from 50 – 80% of approximate crown cover (Queensland Herbarium 2011).
- Several tree species may be present in the canopy at any one site. The species composition may vary depending on the local climate and soil type.
- Some of the more common and widespread canopy tree species are spotted gum (*Corymbia citriodora*), pink bloodwood(*C. intermedia*), white mahogany (*Eucalyptus acmenoides*), broad-leaved stringybark (*E. caliginosa*), Gympie messmate(*E. cloeziana*), narrow-leaved iron-bark (*E. crebra*), broad-leaved iron-bark (*E. fibrosa*) and gum-topped box (*E. moluccana*).
- The understorey is typically grassy with a sparse shrub layer. There can be variation in the species composition and structure of the understorey, which may relate to the local climate, soil type, and management history of the site.
- Understorey shrubs tend to be hard-leaved and relatively fire tolerant, that is they can re-sprout after fire or have hard-coated or hard-capsuled seeds that can survive fire.
- Some of the more common and widespread shrub and small tree species found in eucalypt open-forests are wattles (*Acacia* spp., like *A. crassa, A. crassicarpa, A. disparrima, A. flavescens* and *A. leiocalyx*), she-oaks (*Allocasuarina* spp., like *A. littoralis* and *A. torulosa*) and various shrubby peas (like *Hovea* spp., *Jacksonia* spp. and *Indigofera* spp.).

[2] 'Eucalypt' is used as a collective term for species of *Eucalyptus* and *Corymbia* (bloodwoods) in this guideline.

Eucalypt open-forests tend to occur in areas of moderate rainfall between the wet sclerophyll forests of high rainfall areas, and the eucalypt woodlands of the drier interior (Wardell-Johnson *et al.* 1997). They occur over a large area of eastern Queensland, from the New South Wales border to Cape York Peninsula. In higher rainfall areas, they tend to occur on soils of lower fertility than wet sclerophyll forests (Florence 1996).

Figure 2: Examples of eucalypt open-forest (image credits clockwise from top left: T. Ryan, J. Kemp, M. Laidlaw, DSITIA)

Management of reforestation projects may incorporate non-carbon income streams, such as ongoing grazing or other products like timber. The amount and type of uses that can be incorporated into carbon farming projects will vary depending on the methodology applied. The target density, structure and composition for reforestation will depend upon the balance that managers aim to strike between carbon, biodiversity and other values. The trade-off between trees and pasture is an important example.

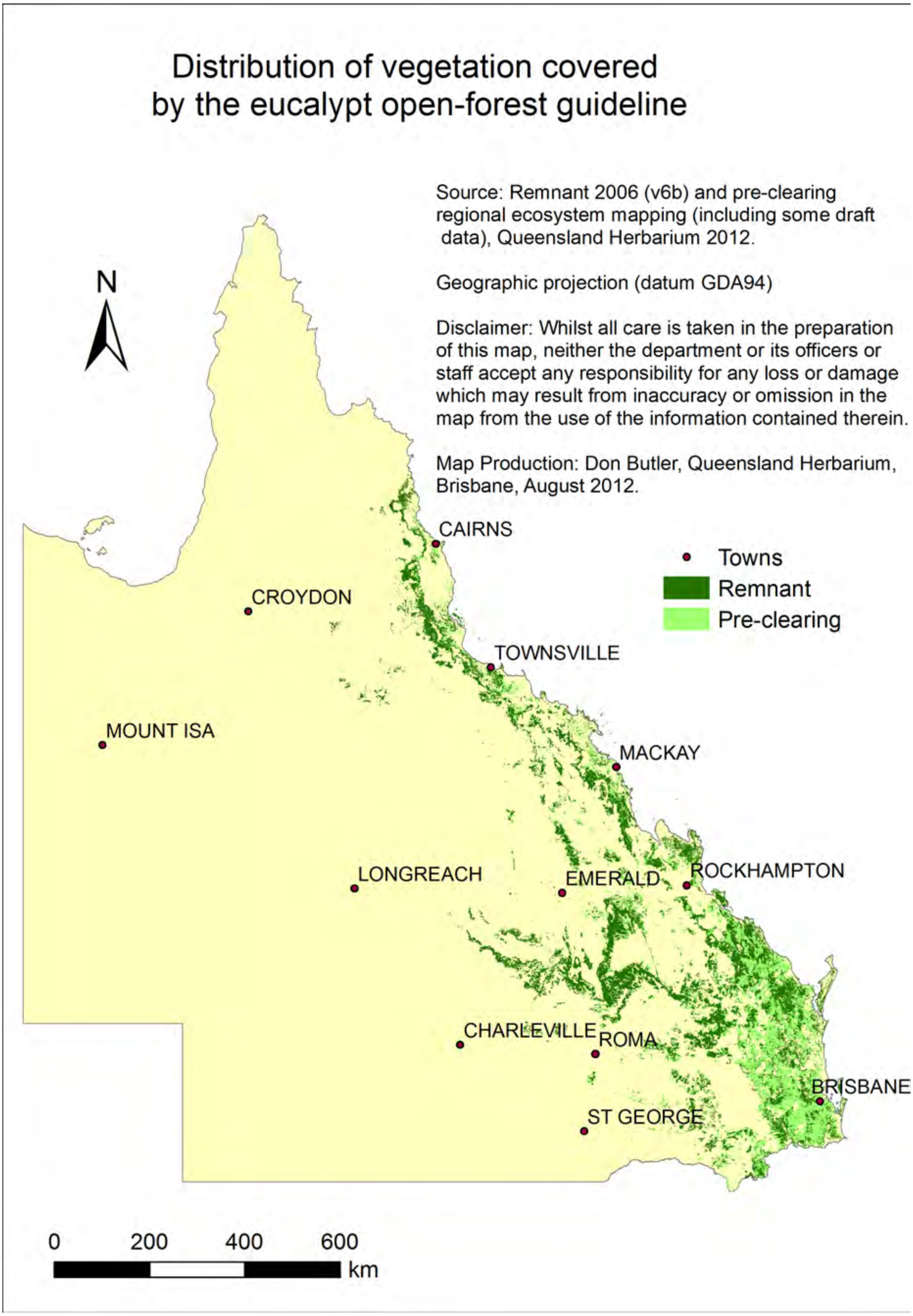


Figure 3: The distribution of eucalypt open-forests covered by this guideline in Queensland

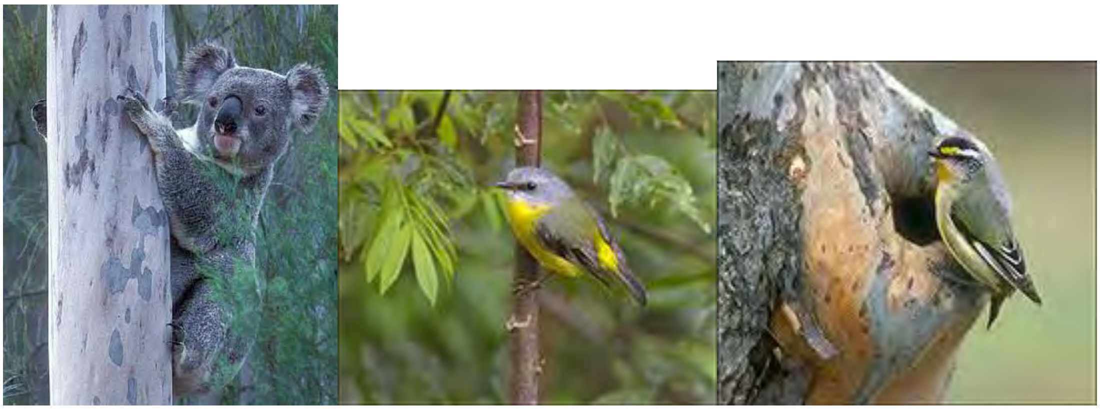


Figure 4: Animal species associated with eucalypt open-forest in Queensland: left: koala (Image: L. Hogan, DSITIA); centre: eastern yellow robin (Image: G. Chapman); right: striated pardalote (Image: G. Chapman)

Figure 5: Plant species associated with eucalypt open-forests in Queensland: Left: *Leionema obtusifolium* (Image: D. Halford, DSITIA): Centre: *Leucopogon recurvisepalus* (Image: J. Clarkson, DSITIA); right: Marlborough blue cycad, *Cycas ophiolitica* (Image: L. Hogan, DSITIA)

Ecology

The restoration and management of eucalypt open-forests are underpinned by what we know about the ecology of this vegetation type including the effects of climate, clearing, grazing, fire and drought. The biology of the dominant canopy trees (*Eucalyptus* and *Corymbia* species) has a large bearing on the ecology of eucalypt open-forests, and their management for carbon accumulation and wildlife conservation. *Eucalyptus* and *Corymbia* are closely related, and in these guidelines the term ‘eucalypt’ is used as a collective term for both genera.

The biology of open-forest eucalypts

The height of an open-forest eucalypt tree is mostly comprised of its single stem, with the crown generally forming less than half of overall tree height (Williams & Brooker 1997). Most open-forest eucalypt species develop a lignotuber in the early months of growth, and this enables them to survive all but the most severe fires, and to regrow rapidly if their crowns are damaged (Florence 1996). Open-forest eucalypts usually flower every year, but flowering season varies within and between species and sites (House 1997). Documented pollinators or visitors of open-forest eucalypts include insects, birds, flying foxes and gliders (House 1997).

Many tropical and subtropical eucalypt species drop their fruits only weeks or months after flowering (Burrows & Burrows 1992; Williams & Brooker 1997) and fire is generally not needed to trigger seed release in tropical eucalypt species (Williams & Brooker 1997).

A study of four forest and woodland eucalypt species in central Queensland found that most seed was released in the warmer months, when the probability of rainfall is greatest (Burrows & Burrows 1992). Eucalypt seed has short term viability on the soil surface due to lack of a hard seed coat, and predation by ants can be significant (Hodgkinson *et al.* 1980;Burrows & Burrows 1992; Stoneman 1994; House 1997). The seed of most open-forest eucalypts does not remain viable in the soil for more than 12 months (Florence 1996).

The recruitment of open-forest eucalypts tends to be ongoing when seed is available (Florence 1996; Bauhus *et al.* 2002). This is because the germination and establishment of seedlings does not require disturbance, or the creation of large canopy gaps. For example, seedlings of spotted gum (*C. citriodora*) established every year between 1959 and 1964 at a site in south-east Queensland without fire or other major disturbance (Henry & Florence 1966). Another south-east Queensland study found that fire and/or inter-tussock spaces were not required for the germination of *E. tereticornis* (Fensham & Fairfax 2006). Therefore, burning to create a seed bed of bare earth does not appear to be necessary for seedling establishment in eucalypt open-forests (Debuse & Lewis 2007). Growth in height may be rapid when open-forest eucalypt seedlings develop on an ash-bed, but these enhanced growth rates may diminish once the overstorey is re-established (Henry & Florence 1966). Furthermore, seedling growth is not always faster in burnt, open sites (Henry & Florence 1966).

Seedling mortality can be high in the weeks immediately following germination, but survivorship increases (sometimes dramatically) once a lignotuber is formed (Henry & Florence 1966), and reaches a critical size (Walters *et al.* 2005; Fensham & Fairfax 2006). As a result, a pool of lignotuberous seedlings and saplings tends to accumulate in the understorey of eucalypt open-forests (Henry & Florence 1966; Walters *et al.* 2005). These plants are capable of withstanding high temperatures, drought, browsing and fires, and may persist for many years (Florence 1996). Reduced availability of water and nutrients did not significantly affect the lignotuber size developed by open-eucalypt forest seedlings (*Corymbia citriodora* subsp. *variegata*, *E. acmenoides* and *E. siderophloia*) in a glasshouse trial (Walters *et al.* 2005).

When mature trees are lost from the canopy, these tend to be rapidly replaced by saplings from the pool of lignotuberous recruits present in the understorey. It has been observed that the creation of canopy gaps can trigger an immediate, and sometimes very substantial growth reaction in lignotuberous seedlings of spotted gum (*C. citriodora*), grey ironbark (*E. drepanophylla*) and forest red gum (*E. tereticornis*) (Henry & Florence 1966).

Dense understorey shrubs (including lantana)

The establishment and survivorship of open-forest eucalypt seedlings may be reduced or prevented by uniformly high densities of understorey shrubs and small trees such as wattles (*Acacia* spp.), as eucalypts are relatively shade intolerant (Stoneman 1994; Florence 1996). This may also explain why there are usually few eucalypt seedlings and saplings present in the understorey of a wet sclerophyll forest, which is often composed of a dense shrub layer, including many species of rainforest origin.

There is some evidence that the survivorship of open-forest eucalypt seedlings may be reduced where there is competition from lantana (*Lantana camara*) (Henry & Florence 1966).

Lantana can develop rapidly in spotted-gum/ironbark forests if fire is absent and soil conditions are suitable and this may restrict the regeneration of eucalypts (Henry & Florence 1966).

Eucalypts have long lifespans (100+ years), so a high rate of seedling recruitment such as every 1 to 10 years is not necessary to ensure the replacement of old trees when they die.

The relatively open structure of eucalypt open-forests usually results in the germination and establishment of sufficient eucalypt seedlings over time to replace old trees. Therefore the control of dense shrubs to allow tree recruitment may only be needed if recruitment is obviously being suppressed over an extended period of time.

Fire

Severe fires may slow the growth of trees, but fires of low to moderate intensity where there is little or no scorch of tree crowns will have little effect on the growth of open-forest eucalypt species (Florence 1996). A study in south-east Queensland found that burning every two to three years did not significantly affect the growth rates of *Corymbia citriodora* subsp. *variegata, E. drepanophylla, E. tereticornis* or *E. acmenoides* (Guinto *et al.* 1999). The same study also found that annual burning had a positive effect on the growth of *E. tereticornis* and smaller *C. citriodora* subsp. *variegata* trees; an apparently negative effect on the growth of larger *C. variegata* trees; and no effect on the growth of *E. drepanophylla* or *E. acmenoides* (Guinto *et al.* 1999).

Fire also has a limited effect on the recruitment of open-forest eucalypts. According to (Henry & Florence 1966), there is no evidence that the loss of well-established lignotuberous eucalypt plants from the regeneration pool is more rapid under an annual-burning regime than in an unburnt forest. The lignotuberous seedlings of five species of open-forest eucalypt (*E. drepanophylla, E. acmenoides, E. tereticornis, E. siderophloia,* and *C. intermedia*) were found to survive equally well in burnt areas as in unburnt areas (Henry & Florence 1966). A Bunya Mountains study also indicated that more than 50% of *E. tereticornis* seedlings will survive burning after 12 months of age (Fensham & Fairfax 2006). This study concluded that regular burning may impede, but not prevent the invasion of eucalypt forest into grassland at the Bunyas (Fensham & Fairfax 2006). A group of species, primarily *E. tereticornis* and the shrubs *Bursaria spinosa* and *B. incana* were especially resilient to fire, showing the lowest levels of mortality and a stable density of small trees, despite repeated burning (Fairfax *et al.* 2009).

Guinto *et al.* (2001) investigated the soil properties of a eucalypt open-forest site in south-east Queensland after more than 40 years of annual burning. They reported no loss of topsoil total nitrogen or carbon, but a significant increase in phosphorous (P), and noted that additional P is likely to be beneficial to plant growth given the relatively low P levels in many Australian forest soils (Guinto *et al.* 2001).

High intensity fires are more likely to kill trees, scorch tree crowns, reduce diameter growth, damage stems, and assist the entry of damaging insects and fungi (Debuse & Lewis 2007).

Grazing pressure

Even relatively intense grazing by wallabies and/or cattle does not appear to prevent the establishment and growth of some open-forest eucalypt species. For example, the expansion of eucalypt forest (dominated by *E. tereticornis* and *E. eugenioides*) into the grassy balds of the Bunya Mountains actually appears to be more substantial in areas where livestock grazing has continued, compared to areas where it has been excluded (Fensham & Fairfax 1996; Fensham & Fairfax 2006).

Grazing by cattle and sheep did not affect the growth and survival of *C. citriodora* saplings in a plantation in Brazil although herds were removed when there was insufficient grass (Couto *et al.* 1995). The plantations in this study had stock added when the eucalypts were six months old and about 2m in height, and trees were remeasured after 18 months (Couto *et al.* 1995).

Shoot removal can kill young seedlings if grazing occurs before they have developed a large enough lignotuber. A glasshouse study which involved defoliating eucalypt seedlings of different ages found that survivorship of eucalypt seedlings (*Corymbia citriodora* subsp. *variegata*, *Eucalyptus acmenoides* and *E. siderophloia*) by resprouting was much higher once they had developed lignotubers larger than about 2.5 mm diameter (Walters *et al.* 2005). This study recommended that to maximise survivorship, seedlings needed to be protected from fire and grazing until their lignotubers were large enough to re-sprout after defoliation (Walters *et al.* 2005). Seedlings of *Corymbia citriodora* subsp. *variegata* developed a lignotuber large enough to survive defoliation after only about four months growth, while *Eucalyptus acmenoides* and *E. siderophloia* needed about six months to develop lignotubers of a similar size (Walters *et al.* 2005). However, it should be noted that this was a glasshouse study and rates of lignotuber development may differ in a field situation.

Clearing

In Queensland, eucalypt open-forests have been cleared including thinning and selective harvesting for timber and to promote increased pasture production. Common methods of killing trees are stem injection of herbicide, ringbarking and mechanical clearing. Open-forest eucalypts are likely to regrow readily after clearing if healthy trees are nearby to provide seed, rainfall is adequate, soil conditions are suitable and dense shrubs do not suppress seedling establishment and growth. Regrowth may arise from the recruitment of new seedlings, but is more likely to develop from root suckers, the resprouting of cut stumps, and from a ‘bank’ of seedlings and saplings that were present before the site was cleared. While this has been problematic for pasture maintenance, it can be useful for farming carbon by reforestation.

The establishment of fewer, larger trees rather than dense thickets of small trees is the best option for maximising carbon (see the ***Farming carbon*** section).

Tree clearing also includes thinning, where some trees are left for timber production and/or shade and shelter. Thinning may increase the rate and amount of carbon accumulated in the remaining trees, but it is often expensive. It may be more cost-effective for landholders to maintain forested areas as distinct paddocks, or as tree strips (e.g. McKeon *et al.* 2008), rather than attempt to maintain low tree density in pastures by resisting the trees' capacity to multiply. Any thinning undertaken while restoring open-forests for carbon should retain the dead timber on site as debris, as this will contribute to carbon storage.

Tree dieback

The decline and premature death of mature eucalypts has been observed in many parts of Queensland (Wylie *et al.* 1992; Fensham & Holman 1999). Tree dieback appears to have a number of causes, and these may result to the death of all or part of the tree. Severe levels of dieback have been recorded in 20 shires in central and southern Queensland (Wylie *et al.* 1992). In this area of Queensland, the indicator species for dieback are considered to be *E. crebra*, *E. drepanophylla*, *E. melanophloia* and *E. tereticornis* (Wylie *et al.* 1992). Bell-miner-associated dieback (BMAD) is most commonly associated with wet sclerophyll forest, but it also affects some areas of open eucalypt forest in south east Queensland (B. McDonald *pers. comm.*).

Dieback is often characterised by cycles of defoliation followed by epicormic growth, reduced flowering, and increasing numbers of bare dead branches in the tree canopy. Initial defoliation may be caused by drought, insects or other factors. In response, there is rapid production of epicormic shoots, which are high in nitrogen, and this allows insects to increase in number, and continue to defoliate the tree (Landsberg & Wylie 1983; Marsh & Adams 1995). Successive generations of insects are then maintained at high densities by the continued regrowth of epicormic shoots (Landsberg & Wylie 1983).

Many factors appear to contribute to tree dieback, including tree clearing, insect herbivory, livestock grazing, salinity and waterlogging, and their effects can vary with locality (Wylie *et al.* 1992; McIntyre 2002). However, this type of dieback is generally more severe in areas of intensive land management (Landsberg & Wylie 1988). A survey of tree dieback in central and southern Queensland found the highest dieback ratings on properties with the largest percentage of their area devoted to improved pasture, and where fertiliser had been used on crops and pastures (Wylie *et al.* 1992).

There are also suggestions that the loss of native animals and plants from rural landscapes may contribute to tree dieback (McIntyre 2002). Some natural insect-controllers (such as echidnas, sugar gliders and wasps) may be unable to regulate insects in cleared landscapes, as the other habitat features that they require like fallen timber and a diversity of understorey shrubs are scarce or absent (McIntyre 2002). Increases in the populations of large, territorial miner birds like noisy miners (*Manorina melanocephala*), yellow-throated miners (*M. flavigula*), and bell miners (*M. melanophrys*) often displace smaller insect-eating birds (Maron *et al.* 2011), and this may cause insect outbreaks and tree dieback (McIntyre 2002,Wardell-Johnson *et al.* 2005), including the syndrome of BMAD. The factors which most influence the abundance of miners appear to vary across ecosystems (Maron *et al.* 2011). While increased abundances of bell miners have been associated with dense understorey vegetation (Wardell-Johnson *et al.* 2005), the abundance of the other miner species may increase the amount of clearing (Eyre *et al.* 2009), or with increased grazing pressure and reduced understorey density (Howes & Maron 2009; Howes *et al.* 2010).

Rainfall

As eucalypt open-forests occur in areas of moderate rainfall they may be less susceptible to droughts than vegetation occurring in the drier parts of Queensland. However, variation in rainfall is still likely to influence rates of tree recruitment and growth, and also fire regimes, in this vegetation type.

Ecological model

The ecological model for eucalypt open-forests (Fig.6) summarises the dynamics of this vegetation type into seven main condition states, and identifies factors that cause transitions between states. Mature eucalypt open-forests are converted into other condition states in the following ways:

- Selective clearing and/or grazing and/or burning within a mature eucalypt open-forest (State 1) can reduce carbon stocks, and lead to an open-forest with limited tree recruitment (State 2), and sometimes with high densities of shrubs (State 3).
- Clearing, in combination with grazing and/or burning, can result in states with canopy trees still present (States 4 and 5), but over time the canopy trees may be completely removed (States 6 and 7).

To restore to a mature open-forest, understorey shrubs may need to be thinned or removed (States 3, 5 and 7), and states without a eucalypt seed source (States 6 and 7) will require direct seeding or tube stock planting of canopy tree species. These transitions will be accelerated if there is adequate rainfall, no clearing and no hot fires[3].

Carbon stocks in a mature eucalypt open-forest (State 1) will be maintained close to their capacity if there is adequate rainfall, no clearing and/or hot fires. Grazing and timber harvesting should be compatible with carbon farming as long as the mortality of mature trees is equal to the recruitment of new trees into the canopy (see ***Managing tree density*** below). The target tree density and vegetation structure for a particular site will depend upon the desired balance between trees, timber, pasture, biodiversity and any other relevant values chosen by the land manager.

In time, climate variability may also alter the potential ‘mature’ structure and floristic composition of eucalypt open-forests. This is because changes in rainfall, temperature, levels of carbon dioxide and other factors may affect the reproduction, growth and competitive ability of the plants and animals that are currently part of the eucalypt open-forest ecosystem. Over time, some species may become difficult to grow on a site they once occupied, because of the effects of climate variability, and these species may become locally extinct. Other native species that were not previously recorded may appear, if conditions become more suitable for them. It is not known how quickly these changes will take place, although changes in the distribution and behaviour of some species have already been observed (e.g. Hughes 2003; Chambers *et al.* 2005; Beaumont *et al.* 2006).

[3] In this guideline, the term ‘hot fire’ is equivalent to a moderate or high severity fire or above. ‘Hot fires’ can occur whenever humidity and soil moisture levels are low, and they most commonly occur in the late dry season. In Queensland, this tends to be in winter or spring. See the Department of National Parks, Recreation, Sport and Racing’s Bioregional planned burn guidelines for definitions of fire severity for Queensland open forests and woodlands http://www.nprsr.qld.gov.au/managing/planned-burn-guidelines.html .

Until more is known about the influence of climate variability on native species, it is best to maintain or restore the native vegetation that occurred on a given site within the last 150 years or so, as this vegetation is most likely to maximise both the sustainable carbon and biodiversity potential of the site. In many cases it will also be the easiest type of vegetation to grow. Another way to buffer your site against the effects of climate variability is to establish and conserve a wide range of native plant and animal species that are associated with the type of vegetation that occurred on your site within the last 150 years or so. If some species become less suited to the conditions and are lost, others should be ready to take their place, and this may minimise any impact on the overall structure and dynamics of the ecosystem.

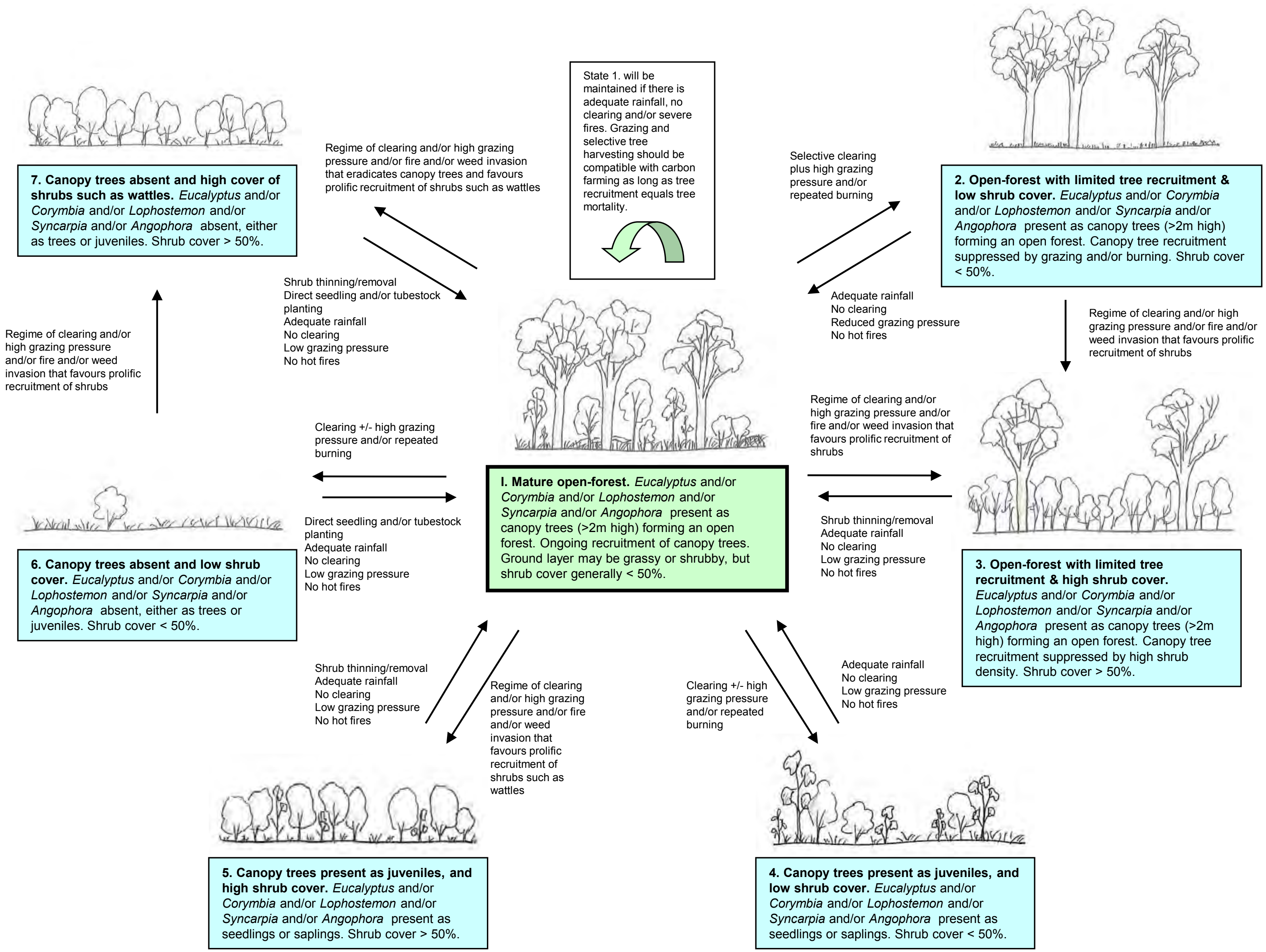


Figure 6: Ecological model for eucalypt open-forests in Queensland

Farming carbon

This guide focuses on managing and accumulating carbon in above-ground plant biomass and coarse woody debris, because they are the most stable and readily verified component of land based carbon stores. However, management to accumulate carbon in above-ground biomass is expected to also increase soil carbon stocks. Biomass is directly proportional to carbon as carbon makes up about 50% of all biomass (Gifford 2000). Carbon farming might not always mean bringing eucalypt open-forests back to their full carbon capacity as soon as possible. Some carbon returns might be traded-off against other land-uses, such as selective timber-harvesting and livestock grazing, which may limit carbon accumulation rates. Selective timber harvesting and low to moderate levels of livestock grazing appear to be compatible with carbon farming in eucalypt open-forests (see ***Management actions*** below).

Above-ground carbon in eucalypt open-forest is stored in living trees shrubs, but also in dead standing trees, fallen timber and litter. Estimates of carbon stocks in living above-ground biomass for eucalypt open-forests range from 86 to 860 tonnes of carbon dioxide equivalent (tCO_2-e) per hectare. The estimated accumulation rate of carbon for living biomass in young regrowing eucalypt open forest for the first 20 years ranges from 1 to 10 t ha^{-1} yr^{-1} which equates to about 2 to 17 tCO_2 per hectare per year.

Carbon storage and tree size

Large trees hold far more carbon than small trees (Table 1) because the amount of carbon held increases exponentially as the trunk diameter of a tree increases (Fig. 7). For example, the carbon held in an average very large tree (~60 cm trunk diameter) is approximately equivalent to that held in nearly 500 smaller trees (~5 cm trunk diameters) (Fig. 8).

Table 1: Amounts of above-ground dry matter, carbon and CO_2 equivalent stored in eucalypts of different diameters; based on Williams *et al*. 2005b; note figures are approximate only

Tree dbh (cm)	Dry matter (kg)	Carbon (kg)	CO_2 equivalent (kg)
5	5.3	2.5	9.7
30	458	215	790
60	2565	1206	4424

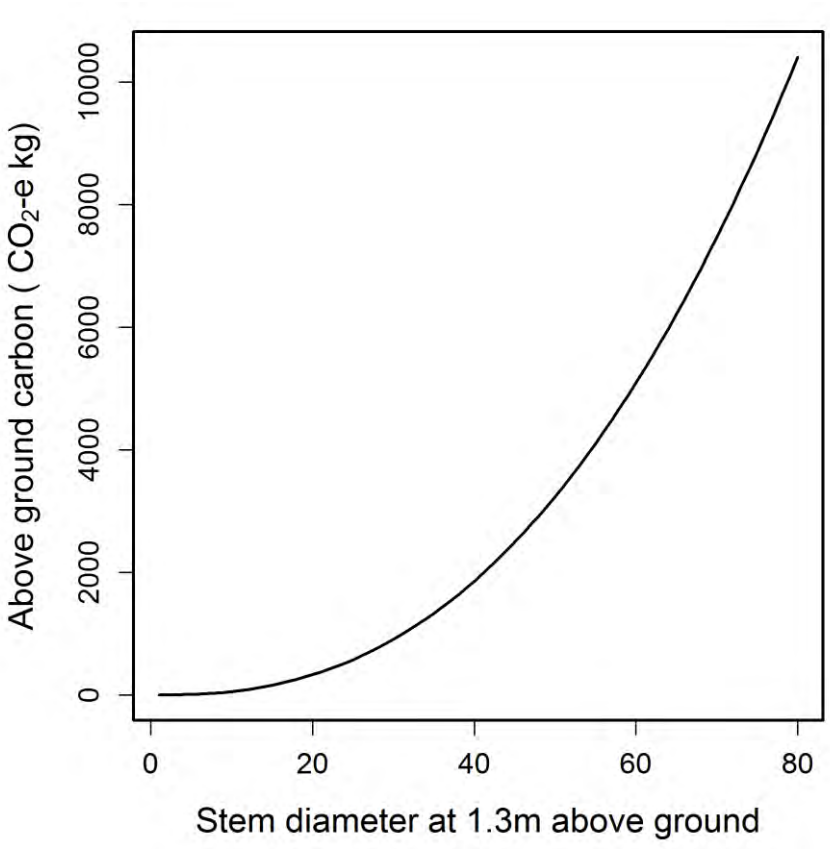


Figure 7: Relationship between eucalypt trunk diameter and above-ground carbon; based on Williams et al. 2005a

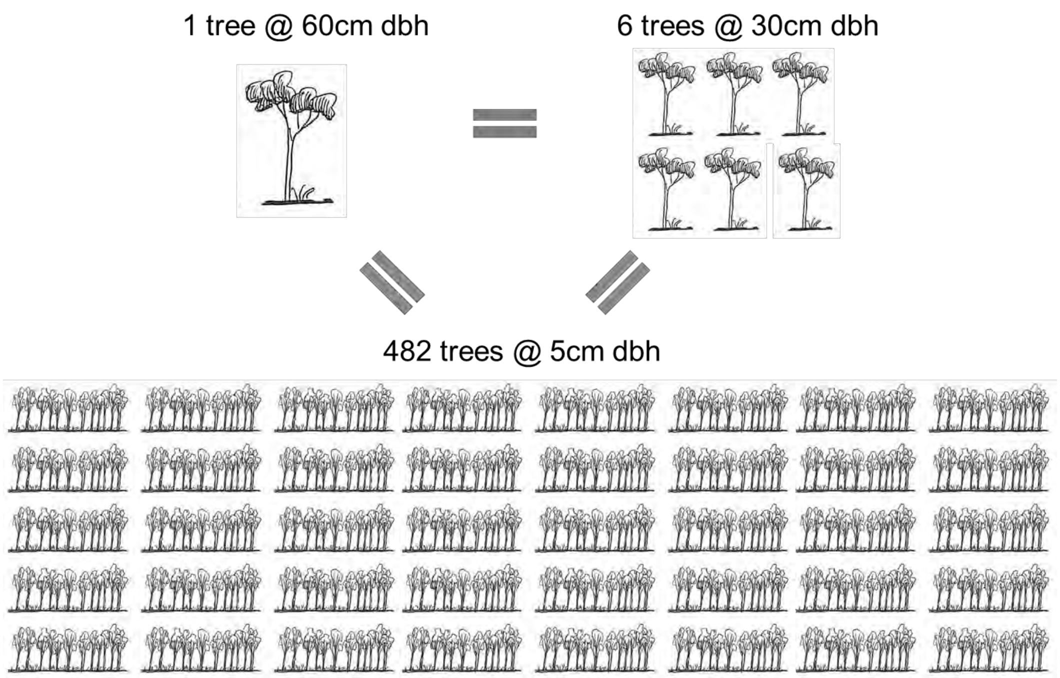


Figure 8: Carbon equivalence and tree size, approximately the same amount of carbon is stored in one large eucalypt as several hundred small trees: based on allometry from Williams *et al.* 2005a; dbh = main stem diameter at 1.3 m height

Trade-offs between trees and pasture

It is important to note that increasing the basal area of trees tends to decrease pasture yield. This has been observed for a variety of woodland types in Queensland (Fig. 9), and the same trend is likely to apply to eucalypt open-forests. It should be possible to combine carbon farming of regrowth with livestock production[4], but landholders should consider how increased tree growth may impact on their pasture yield.

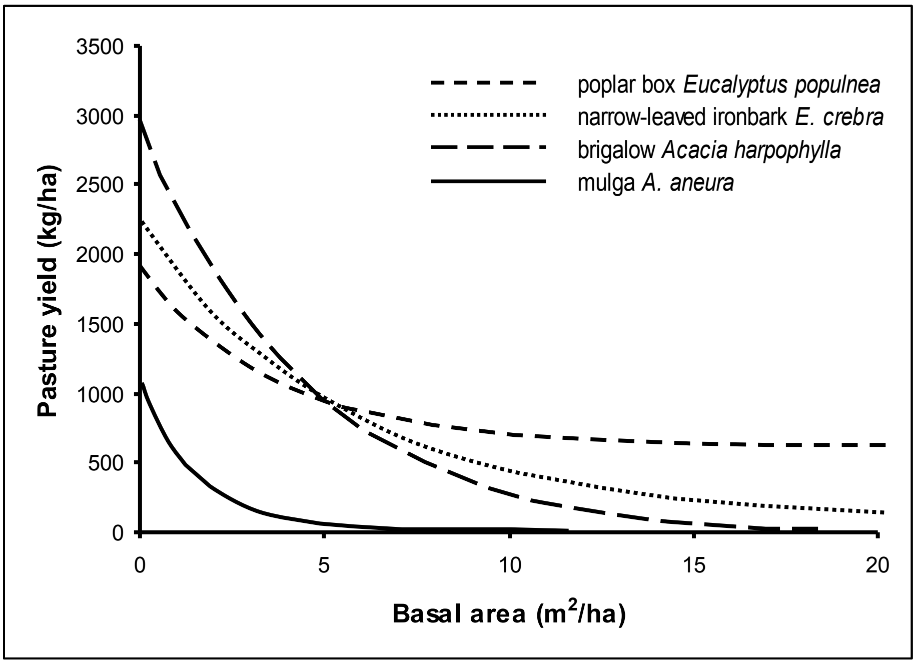


Figure 9: Relationships between tree basal area and pasture yield for a range of woodland tree species from sites in Queensland; redrawn from Burrows 2002; data originally derived from Beale 1973 (*A. aneura*); Scanlan & Burrows 1990 (*E. populnea*) and (*E. crebra*), Scanlan 1991(*A. harpophylla*)

Grow big trees to maximise carbon

A few big trees can hold far more carbon than a large number of small or medium trees (Fig. 8). So it is in the interests of carbon farming to maximise the height and diameter of existing trees, which may be achieved by reducing tree density in dense regrowth. This may involve the selective thinning of smaller trees, or allowing drought and competition among trees to result in natural rates of tree dieback and thinning.

Pasture yield is still likely to be reduced by increasing tree basal area (Fig. 9), but a few large trees will hold far more carbon than many small ones, for the same basal area (Fig. 10).

[4] This will depend on the Carbon Farming Initiative or Emissions Reduction Fund methodology being applied

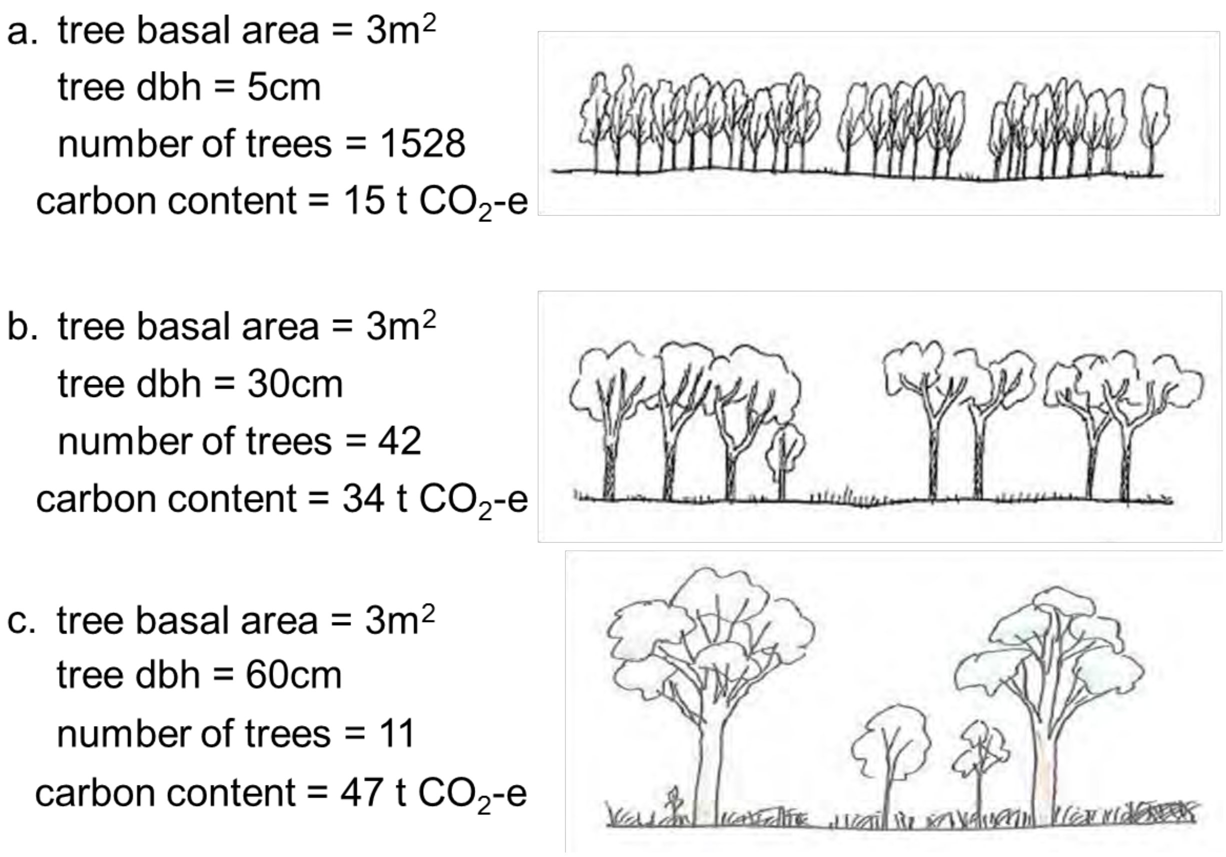


Figure 10: Potential variations in tree size, density and CO_2 equivalent stored for the same basal area; a high density of small trees (a) stores less CO_2 equivalent than lower numbers of larger trees (b and c); based onWilliams *et al.* 2005a

Limits to carbon accumulation

Biomass and therefore carbon accumulation in eucalypt open-forest may be limited by rainfall, clearing, hot fires, continuous high grazing pressure and dense understorey shrubs and small trees such as wattles (Table 2). The total amount of carbon stored by eucalypt open-forest, and the rate of carbon accumulation, can be maximised by removing these limits where possible.

Carbon accumulation in regenerating eucalypt open-forests is limited by:

Rainfall - Variation in rainfall is likely to influence rates of tree recruitment and growth, and also fire regimes, in eucalypt open-forest.

Clearing - Clearing of eucalypt open-forest will reduce the rate of carbon gain, decrease the capacity of the vegetation to store carbon, and produce a net carbon loss. Careful selective harvesting of trees is still compatible with carbon farming, as this will not damage the health or growth potential of the forest. However, selective harvesting will slow the rate of carbon gain, and reduce the amount of carbon stored.

Hot fires - Hot fires[5] (fires of moderate to high severity, and above) can damage and kill adult trees, and consume the carbon in trees, shrubs, dead wood and litter. This reduces carbon stores and slows carbon accumulation rates. Although seedling and adult eucalypts can survive low to moderate severity fires once a lignotuber is formed (Wardell-Johnson et al. 1997; Fensham et al. 2008), the loss and replacement of above-ground parts will slow growth rates. Therefore, it is recommended that moderate to high severity fires are avoided when farming carbon in eucalypt open-forests.

Continuous high grazing pressure – Carbon farming in eucalypt open-forests appears to be compatible with low to moderate levels of grazing pressure which do not suppress the recruitment and growth of eucalypts. Continuous high grazing pressure is not recommended if it prevents the recruitment of trees or leads to soil degradation. But strategic grazing management that reduces fire risk, and allows tree recruitment is likely to maximise carbon storage and accumulation rates. However, more information is needed to determine grazing regimes including timing and stocking rates that will allow the optimum production of trees.

Dense understorey shrubs -The establishment and survivorship of open-forest eucalypt seedlings may be reduced or prevented by high densities of understorey shrubs, and this will slow carbon accumulation rates and limit carbon stores.

Table 2: Summary of limits to carbon accumulation for eucalypt open-forests

Site features		Effect on carbon	
		Total carbon stored	Rate of carbon gain
	Rainfall	↑	↑
	Clearing	↓	↓
	Hot fires	↓	↓
	Continuous high grazing pressure	↓	↓
	Dense understorey shrubs	↓	↓

[5] In this guideline, the term 'hot fire' is equivalent to a moderate or high severity fire or higher. 'Hot fires' can occur whenever humidity and soil moisture levels are low, and they most commonly occur in the late dry season. In Queensland, this tends to be in winter or spring. See the Department of National Parks, Recreation, Sport and Racing's Bioregional planned burn guidelines for definitions of fire severity for Queensland open forests and woodlands http://www.nprsr.qld.gov.au/managing/planned-burn-guidelines.html

Wildlife conservation

Figure 11: Some animal species associated with eucalypt open-forests. Top Left: Greater glider (*Petauroides volans*)(Image: L. Hogan, DSITIA); Top Right: Yellow-faced honeyeater (*Caligavis chrysops*)(Image: Graeme Chapman); Bottom: Lively rainbow skink (*Carlia vivax*)(Image: C. Dollery).

Eucalypt open-forests in Queensland provide habitat for many different types of native plants and animals, including at least 36 threatened or priority species (Queensland Herbarium 2011). Examples of native species that occur in eucalypt open-forests are the greater glider, yellow-faced honeyeater and lively rainbow skink (Fig. 11) and the Byfield fern, *Cycas megacarpa*, and the Plunkett mallee (Fig. 12).

Most management actions that will accumulate carbon in eucalypt open-forests such not clearing regenerating trees, excluding hot fires, and reducing grazing pressure will also benefit wildlife. Habitat features that will help to conserve wildlife in eucalypt open-forests include different types of shelter and a good and varied supply of food. Beneficial actions include the removal or control of weeds and feral animals. Landscape features including the size and shape of habitat patches and their distance from each other will also influence the potential of a site to conserve wildlife.

Figure 12: Plant species associated with eucalypt open-forests: Left: Byfield fern (*Bowenia serrulata*)(Image: R. Melzer); Middle: *Cycas megacarpa* (Image: P. Forster, DSITIA); Right: Plunkett mallee (*Eucalyptus curtisii*)(Image: D. Butler).

Limits to wildlife conservation in eucalypt open-forests

Shelter and food

Trees and shrubs, including a variety of size and age classes

Trees and shrubs provide shelter and feeding sites for many animals, including insects, mites and spiders and arboreal mammals such as gliders. Bird species that forage mainly on the trunks and foliage of shrubs and trees include pardalotes, thornbills and treecreepers. The diet of some arboreal mammals consists mainly of eucalypt leaves like the koala and greater glider while others rely mostly on sap, flowers and insects such as the yellow-bellied glider, sugar glider and squirrel glider. Yellow-bellied gliders (*Petaurus australis*) make characteristic incisions in the stems of eucalypts to feed on sap, and these feeding points are then utilised by other gliders, birds and insects.

More wildlife will be supported if a variety of tree and shrub species, sizes and ages are present, rather than a monoculture or forest with a simple age structure. For example, studies in southern Queensland have shown that yellow-bellied gliders prefer certain tree species for sap feeding (i.e. *E. longirostrata* and *E. biturbinata*) although other eucalypt species may also be used, and large trees (greater than 40 cm dbh) are preferred (Eyre & Goldingay 2003; Eyre & Goldingay 2005). Other tree species (*E. tereticornis* and *C. citriodora*) also provide important sources of nectar and pollen for the yellow-bellied glider (Eyre & Goldingay 2005) and these tree species are preferred for denning by the greater glider in southern Queensland (Eyre 2006). The greater glider also is known to feed on a variety of eucalypts including *E. acmenoides*, *E, moluccana*, *E. fibrosa* and *C. citriodora* (Eyre 2006), and prefers to forage in large trees (>30 cm dbh) (Comport *et al.* 1996; Smith *et al.* 2007).

A study in the temperate woodlands of southern New South Wales found that different species of birds preferred different types of regrowth (plantings, resprout regrowth, seedling regrowth and old growth), and this was most probably related to differences in structural complexity among regrowth types

(Lindenmayer *et al.* 2012). This suggests that more bird species will be supported if a range of vegetation growth types are represented in a given farmland area.

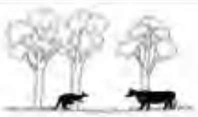
Figure 13: The yellow-bellied glider (*Petaurus australis*) creates characteristic v-shaped incisions to feed on eucalypt sap (Image: L. Hogan, DSITIA)

A diverse suite of tree and shrub species that flower and fruit at different times is more likely to provide food sources such as nectar, pollen, fruit and insects, throughout the year for birds and other animals. For example, seasonal movements of the threatened grey-headed flying fox have been associated with the flowering patterns of open-forest eucalypts such as *C. citriodora* and *E. tereticornis* (House 1997).

An extraordinarily large number of arthropod species that is, insects, mites and spiders are found on open-forest eucalypts. For example, a New South Wales study recorded 726 species of arthropods from *Eucalyptus crebra* and 641 species from *E. moluccana* (Majer *et al.* 2000). Only 40% of species occurred on both species of eucalypts, so the actual species richness of the eucalypt forest is probably much higher (Majer *et al.* 2000), with each additional species of eucalypt likely to support at least some additional arthropod species.

Shrubs provide important nesting and foraging sites for small birds (Barrett 2000), and different species of shrubs support different assemblages of insects (Peeters *et al.* 2001).

Table 3: Summary of limits to wildlife conservation in eucalypt open-forests

Limits to wildlife conservation	Effect on wildlife	
	Total number of species	Total number of individuals
Range of shelter options e.g. tree hollows, fallen timber, shrubs, rocks	↑	↑
Good supply of food e.g. insects, nectar, pollen, seeds, leaves, small animals	↑	↑
Landscape features Large patch size, small edge-to-area ratio, close to other patches	↑	↑
Competitors and predators e.g. weeds, feral animals, aggressive native animals	↓	↓
 **Clearing**	↓	↓
 **Hot fires**	↓	↓
 **Continuous high grazing pressure**	↓	↓
 **Dense understorey shrubs**	↑	↑

Tree hollows

Many native animals use tree hollows for shelter and nesting, and some also feed on prey found in hollows (Gibbons & Lindenmayer 2002). Open-forest eucalypts tend to increase in diameter and form hollows as they age (Wormington *et al.* 2003; Eyre *et al.* 2010). For example, in the hardwood forests of Queensland's Brigalow Belt, live trees do not tend to form hollows until they are > 60 cm dbh, that is, diameter at breast height, 1.3 m above ground (Eyre *et al.* 2010), which probably equates to an age of 200 to 300 years or more. Animals that use tree hollows in eucalypt open-forests include parrots, treecreepers, bats and gliders.

The greater glider (*Petauroides volans*) has one of the highest known demands for hollows of any arboreal marsupial that inhabits eucalypt open-forests (Smith *et al.* 2007). A study in Barakula State Forest found that individual greater gliders used from 4 to 20 den trees, and it was likely that the low availability of den trees (~0.8 trees ha^{-1}) was linked to the low population density of gliders at this site (Smith *et al.* 2007). Populations of squirrel gliders (*Petaurus norfolcensis*) in the greater Brisbane area are also likely to be limited by low densities of tree hollows within floristically suitable habitat (Rowston *et al.* 2002).

Valuable shelter can be provided for wildlife by retaining large trees (which are more likely to contain or form hollows). Nest boxes can be provided if hollows are absent or scarce. Hollow bearing trees are susceptible to fire, so it can be a good idea to rake litter away from large habitat trees before application of management fires, and to only conduct burns when soil moisture is high.

Fallen timber

Fallen timber can provide shelter and feeding areas for birds (Barrett 2000), reptiles, frogs, mammals (Lindenmayer *et al.* 2003) and invertebrates. A number of bird species such as robins and fantails use fallen timber as platforms to view, and then pounce on, prey on the ground (MacNally *et al.* 2001). Treecreepers and thornbills often collect insects from fallen timber or the ground nearby (MacNally *et al.* 2001).

It can be tempting to collect fallen timber for firewood, or just to ‘clean up’, but leaving it in place will help to retain water and nutrients, and ease housing and food shortages for wildlife.

Ground cover

Ground cover is essential for the survival of many reptile, mammal and ground-nesting/foraging bird species by providing foraging areas and protection from predators and the elements (Martin & Green 2002, Price *et al.* 2010). Components of ground cover can include large grass tussocks, fallen timber and leaf litter.

Mistletoe

Mistletoe is a parasitic plant that forms clumps on the branches of trees and shrubs, and provides nectar, berries and nesting sites for many animal species (Watson 2001). Mistletoe can provide nectar and berries at times when these foods are scarce in the landscape (Watson 2001).

Rocks

Surface rocks and piles of boulders are important habitats for animals like reptiles. Rocks embedded in the soil may provide animals protection from predators and fires (Lindenmayer *et al.* 2003). Some plant species may only be found in association with rocky areas.

Leaf litter

Litter such as fallen leaves, bark and twigs, provides shelter, nesting sites, and foraging sites for many invertebrates, birds, reptiles and small mammals.

Invertebrates

Invertebrates include insects, spiders and other small animals with six or more (or no) legs. A diversity of foraging habitats such as fallen timber, trees, shrubs, leaf litter will support a variety of invertebrates which can provide food for other animals, pollinate plants, disperse seeds, and assist with litter decomposition and nutrient cycling.

Fungi

Many Australian animals eat fungi especially those that produce fruiting bodies underground like truffles (Claridge 2002, N. Fechner *pers. comm.*). Animals that eat fungi include rodents, reptiles, birds, invertebrates and marsupials like potoroos, bettongs, wallabies, kangaroos, wombats, and possums. Some fungi also enter into symbiotic relationships with native plants (Claridge & May 1994, Claridge 2002), and many of the plant genera that are common in eucalypt open-forests are known to form symbiotic relationships with fungi (N. Fechner *pers. comm.*). It is not known exactly how abundant or diverse fungi are in eucalypt open-forests, or how important they are as a food source to animals, or as symbionts and decomposers of plants. Research is needed to better understand the importance of fungi for wildlife conservation in eucalypt open-forests, and how to best manage this resource.

Landscape features

Large patch size

Small patches of habitat may be able to support populations of some plant and animal species like invertebrates and lizards (Abensperg-Traun *et al.* 1996; Smith *et al.* 1996), but their long-term viability may be questionable, and larger patches are generally better for conserving wildlife (Saunders *et al.* 1991; Bennett 2006). For example, the occurrence of koalas in south east Queensland was found to increase with habitat patch size (McAlpine *et al.* 2006). Patches of remnant vegetation must be large if they are to support viable populations of most mammal species because mammals typically occur at low population densities, and individuals may require large areas of habitat for survival (Cogger *et al.* 2003).

Small edge-to-area ratio

Forest patches that are rounded in shape suffer fewer edge effects than patches of a similar size that are long and thin. Edge effects include increased exposure to weed invasion, predation, wind, sun and temperature, and all of these can have important impacts on wildlife (Saunders *et al.* 1991; Bennett 2006). For example, a southern Queensland study predicted that yellow-bellied gliders were more likely to occur in regular shaped habitat patches compared to linear corridors (Eyre 2007), and this was probably linked to the biology of this species. Yellow-bellied gilders maintain large territories, and rely on widely-dispersed food resources like sap trees (Eyre 2007). Therefore the time spent travelling between sap trees, and presumably the associated predation risk, is minimised if a home territory can be accommodated within a compact, regular-shaped habitat patch rather than spread out along a habitat patch that is long and thin.

Close to other patches

Many animals like invertebrates, reptiles, and forest-dependent mammals are unable to move large distances between suitable patches of habitat (Saunders *et al.* 1991) or face increased risk of predation if they attempt to do so (Cogger *et al.* 2003). A south east Queensland study found that koala occurrence decreased with the distance between forest patches, and the configuration of remnant forest became increasing important as the area of habitat declined (McAlpine *et al.* 2006). Plant dispersal into new patches, and pollination between existing plant populations, can also be restricted by the distance between habitat patches.

How much of the landscape is cleared

The amount of suitable habitat remaining in a landscape has a large influence on the survival of wildlife (Boulter *et al.* 2000, Smith *et al.* 2012). Small patch size and large distances between patches will have stronger negative impacts on birds and mammals if more than 70% of the landscape has been cleared of suitable habitat (Andren 1994). In southern Queensland, densities of greater gliders were predicted to decline if more than 15% of the landscape had been cleared (Eyre 2006).

There is also an interaction between grazing and how much of the landscape is cleared, as cattle tend to congregate in remnant patches of woody vegetation, particularly where they are surrounded by cleared land (Fairfax & Fensham 2000) and this increases trampling and the opportunistic grazing of shrubs and herbs.

Competitors and predators

Weeds and feral animals

Weeds and feral animals are a major threat to wildlife in Australia (Williams & West 2000, Natural Resource Management Ministerial Council 2010). Since eucalypt open-forests are spread over a large area of Queensland they are subject to a variety of weeds like lantana, cactus species and rubber vine, and feral animals like foxes, pigs and goats. The impact of these species on wildlife will vary considerably between sites, so the type and urgency of management actions should be determined on a site-by-site basis.

Aggressive native species

Noisy miners and yellow-throated miners are large, aggressive honeyeaters found throughout much of Queensland. A recent literature review revealed that the density or presence of miners in woodlands was the factor which most consistently influenced the richness, abundance and assemblage composition of woodland birds in eastern Australia (Maron *et al.* 2011), and the noisy miner appears to be the only large-bodied bird species that depresses the occurrence of small-bodied bird species over a range of districts from Victoria to Queensland (MacNally *et al.* 2012). Studies in eucalypt open-forest in the southern Brigalow Belt found that noisy miners had a substantial negative effect on small passerine bird abundance, species richness and distribution (Maron & Kennedy 2007, Eyre *et al.* 2009). Small bird species that characterised sites where the noisy miner was absent included the eastern yellow robin and striated pardalote (Eyre *et al.* 2009).

Noisy miners were found to be most abundant in intensively grazed forest with minimal mid-storey and a low volume of coarse woody debris (Eyre *et al.* 2009). Therefore a reduction in grazing pressure in eucalypt open-forest may benefit small passerine birds by moderating noisy miner abundance (Eyre *et al.* 2009).

Grazing pressure

Increased grazing pressure has been linked to a decreased abundance of understorey shrubs, at least partly because of the frequent low-intensity burns associated with stock management in open eucalypt forests (Eyre *et al.* 2010). The same study also found that dead trees with hollows were less abundant in more intensively grazed sites (Eyre *et al.* 2010). Although grazing pressure probably has a direct negative impact on small passerine birds, it seems that the encouragement of noisy miners via increased grazing pressure has a larger effect (Eyre *et al.* 2009). Noisy miners were most abundant in intensively grazed forest, and a reduction in grazing pressure in eucalypt open-forest may benefit small passerine birds by moderating noisy miner abundance (Eyre *et al.* 2009).

The impact of grazing on ant communities in open-forests is unclear, although an experimental release from grazing pressure for 36 months did not result in a detectable significant difference in ant communities (Vanderwoude & Johnson 2004).

Clearing and selective harvesting

Clearing that converts open-forest to pasture has a large negative effect on many animal and plant species that are associated with this vegetation type. A study in south-east Queensland showed that there was significantly lower numbers of bird species and arthropod orders, and abundances of mammals, beetles and woodlice, in cleared areas compared to adjacent mature forest areas (Green & Catterall 1998). It appears that several decades of regeneration would be necessary before many forest-dependent species were supported in these formerly cleared areas (Green & Catterall 1998).

Bird assemblages also differ between cleared and remnant forest areas, as the relative density of many small bushland birds like pardalotes and robins is significantly higher in forest and woodland areas (Catterall *et al.* 1998). Clearing that results in the loss and fragmentation of habitat has also been identified as a threat to native mammal species such as the northern spotted-tailed quoll *Dasyurus maculatus gracilis* (Burnett & Marsh 2004).

Although selective harvesting can be compatible with wildlife conservation, some practices can also have negative effects on native animals. For example, selective harvesting can alter the structure of a forest to create stands dominated by younger and smaller trees (Eyre & Goldingay 2005), and past forestry practices have also resulted in low densities of living hollow-bearing trees in many Queensland production forests (Smith *et al.* 2007; Eyre *et al.* 2010). This has a negative impact on native animals that rely on large trees, and hollows, for food and shelter. For example, yellow-bellied gliders prefer to feed on large trees (greater than 40 cm dbh)(Eyre & Goldingay 2005) and both yellow-bellied and greater gliders nest in hollows, which are more likely to be found in large trees.

Living trees with hollows are an important resource for hollow-dependent animals, as these trees will generally persist and provide hollows for longer than dead trees with hollows. Once the density of large trees in an area drops below a critical threshold, it becomes very difficult for viable populations of these glider species to persist. In southern Queensland, it is estimated that approximately three hollow-bearing trees per hectare are required to maintain one greater glider in a three hectare area (Eyre 2006).

In contrast, ant communities were found to be highly resilient to timber harvesting at a site in south-east Queensland, with no significant differences in species richness or abundance detected between logged and unlogged plot (Vanderwoude & Lobry De Bruyn 2000). It appears that the fluctuations in shading caused by logging were no greater than seasonal fluctuations, including changes in tree canopy growth (Vanderwoude & Lobry De Bruyn 2000).

Nectar is another resource that can be affected by logging, with flow-on affects for the numerous animal species that are reliant on nectar. A study in southern New South Wales found that mature spotted gum (*C. maculata*) forest produced almost ten times the amount of sugar per hectare as recently logged forest, with regrowth forest somewhere in between (Law & Chidel 2008). Therefore it is likely that the retention and restoration of mature eucalypt trees is likely to improve food resources for nectar-feeding animals on a per-hectare basis.

Selective logging in Queensland eucalypt open-forests is often associated with livestock grazing, so the separate impacts of these factors can be difficult to tease apart (Goodall *et al.* 2004). For example, the mean abundance of small passerine birds was found to be higher in unlogged and lightly grazed treatments than the logged, heavily grazed treatments (Eyre *et al.* 2009).

Fire

Many plant species that occur in eucalypt open-forests are fire tolerant, and may possess thick bark, woody fruits, hard-coated seeds and the capacity to re-sprout after fire (Florence 1996). However, hollow-bearing trees (living or dead) with senescent crowns are sensitive to fire, and are a fragile resource for this reason (Eyre *et al.* 2010). In particular, the density of dead trees with hollows in eucalypt open-forests is strongly reduced by fire both high-intensity wildfires and less-intense but frequent burns that occur approximately every two to five years associated with grazing management (Eyre *et al.* 2010). This has a negative impact on animal species that rely on hollows.

Small bird species appear to be negatively affected by fire in the spotted-gum forests of the southern Brigalow Belt through competition with the noisy miner (Maron & Kennedy 2007). The species richness and abundance of small passerine birds was significantly higher in spotted gum sites with a regenerating cypress pine and buloke (*Allocasuarina luehmannii*) understorey than those with a more open understorey. This variation in understorey structure was due largely to the higher intensity of prescribed burns experienced by the more open sites, and the more open sites also had higher abundances of noisy miners. This study suggests that long-term exclusion of fire from spotted gum forest which encourages the regeneration of subdominant tree species may be beneficial to small passerine bird species, and recommends spatial patchiness of fire regimes (Maron & Kennedy 2007).

The species richness and relative density of reptiles was found to be higher in dry sclerophyll forest that was unburnt for about 50 years than in forest that was burnt annually or periodically every two to five years (Hannah *et al.* 1998). Fine litter and logs were more common in the unburnt forest, and reptiles were significantly correlated with the percentage cover of fallen logs at the microhabitat scale. Burning consumes litter, and either consumes fallen logs or makes them unsuitable as sheltering sites for reptiles. Mosaic burning to maintain structural diversity for a range of reptile species is recommended (Hannah *et al.* 1998).

Table 4:Habitat values for selected eucalypt open-forest species

		Tree hollows, cracks & crevices	Fallen timber	Trees & shrubs	Nectar	Litter	Rocks	Insects
Mammals								
Gould’s wattled bat	*Chalinolobus gouldii*	✓		✓				✓
spotted-tailed quoll	*Dasyurus maculatus*	✓	✓	✓		✓	✓	✓
yellow-bellied glider	*Petaurus australis*	✓		✓	✓			
koala	*Phascolarctos cinereus*			✓				

		Tree hollows, cracks & crevices	Fallen timber	Trees & shrubs	Nectar	Litter	Rocks	Insects
grey-headed flying-fox	*Pteropus poliocephalus*			✓	✓			
Birds								
Yellow-faced honeyeater	*Caligavis chrysops*			✓	✓			✓
Mistletoe bird	*Dicaeum hirundinaceum*			✓	✓			
Eastern yellow robin	*Eopsaltria australis*		✓	✓				✓
Barking owl	*Ninox connivens*	✓		✓				
striated pardalote	*Pardalotus striatus*	✓		✓				✓
grey fantail	*Rhipidura fuliginosa*		✓	✓				✓
Reptiles								
lively rainbow skink	*Carliavivax*		✓			✓	✓	✓
common dtella	*Gehyra dubia*	✓		✓				✓
frilled lizard	*Chlamydosaurus kingii*	✓	✓	✓		✓	✓	✓
Friendly sun skink	*Lampropholis amicula*					✓		✓
Black-tailed monitor	*Varanus tristis*	✓	✓	✓		✓	✓	✓
Frogs								
common green tree frog	*Litoria caerulea*	✓	✓	✓			✓	✓
desert tree frog	*Litoria rubella*	✓		✓				✓
spotted grass frog	*Limnodynastes tasmaniensis*		✓				✓	✓
Plants			✓			✓	✓	

Some animal species that occur in eucalypt open-forests also appear to be relatively tolerant of fire. For example, a study in a south-east Queensland open forest found that the ant communities of areas that were frequently burnt at annual or 2-3 year intervals were significantly different from those of long-term unburned areas (Vanderwoude & Johnson 2004).

Ant abundance, species richness and the relative abundance of Dominant Dolichoderinae were significantly lower in areas of lower fire frequency, and the relative abundance of opportunistic species increased (Vanderwoude & Johnson 2004). However, ant community structure of the frequently burnt areas began to resemble that of the infrequently burnt site after only three years of fire exclusion (Vanderwoude & Johnson 2004), suggesting that native ants are relatively resilient to fire in eucalypt open-forests.

Probably the best fire management for wildlife conservation in eucalypt open-forests is to maintain a range of burning practices that create a fine-scale mosaic of fire histories in the landscape, including unburnt refugia (Debuse & Lewis 2007). General fire guidelines for maintaining the overall biodiversity of regional ecosystems are provided in the Regional Ecosystem Description Database (REDD, Queensland Herbarium 2011). The Department of National Parks, Recreation, Sport and Racing also provides practical fire management advice through 13 bioregional planned burn guidelines (http://www.nprsr.qld.gov.au/managing/planned-burn-guidelines.html).

Dense understorey shrubs

A relatively high density of large trees and stems in the mid-storey is an important habitat feature for small passerine birds, partly through the associated reduction in noisy miner abundance (Eyre *et al.* 2009). High fire frequency and intense grazing pressure should be avoided if the aim of management is to encourage areas with high shrub densities.

Although uniformly high densities of understorey shrubs can suppress the recruitment of eucalypts, a compromise can be reached by providing some open areas for eucalypt recruitment if needed. Also, eucalypts have long lifespans, so continuous tree recruitment is not needed, as long as sufficient young trees are present to replace old trees, and a seed supply is maintained by retaining mature trees. The control of dense shrubs to allow tree recruitment may only be needed if recruitment is obviously being suppressed.

Management actions

This section is intended to help land managers create an action plan to achieve their goals. This can be farming carbon, conserving wildlife, or a combination of both.

To **maximise carbon** (by restoring the site to State 1 in Fig. 14), the management aims for all states are:

- Maximise the height and diameter of existing trees (within the productivity constraints of the site);
- Increase the density of large trees to reach the typical tree density for the vegetation type. Alternately, managers can choose a lower target tree density, but this will prevent the site reaching its maximum carbon state.
- Ensure that the mortality rate of large trees is equal to the recruitment of new trees into the canopy, by allowing seedlings and saplings to develop into trees.

The management aims for **conserving wildlife** are the same as those for maximising carbon (above), with the addition of:

- Avoid actions that kill or injure wildlife like clearing.

- Provide a range of shelter options and food resources for wildlife.
- Manage fire and grazing to allow ongoing recruitment of all plant species.
- Protect and restore landscape features that support wildlife.
- Control competitors and predators that threaten wildlife like feral animals, weeds, and aggressive honeyeaters.

Rainfall and temperature will have a large influence on the potential for reforestation and carbon accumulation on your site. However, other factors, such as fire and grazing, may also require management. The history of the site will generally determine the amounts of initial effort and ongoing maintenance needed to restore it.

To determine which actions apply to your site:

1. Identify the condition state of your site by referring to Fig. 14.
2. Select whether your goal is farming carbon, conserving wildlife, or both.
3. Compile a list of actions from Tables5 and 6 that apply to both the condition state, and goal of your site (either ‘carbon’, ‘wildlife’, or both).
4. Refer to the “Managing tree density” section (following Table 6) for more details about how to achieve target tree densities using strategic grazing and fire management.

More information on fire management and descriptions of fire severity classes can be found in the Department of National Parks, Recreation, Sport and Racing’s bioregional planned burn guidelines (2012a; 2012b), and in Debuse and Lewis' *Using fire in spotted gum - ironbark forests for production and biodiversity outcomes* (2007).

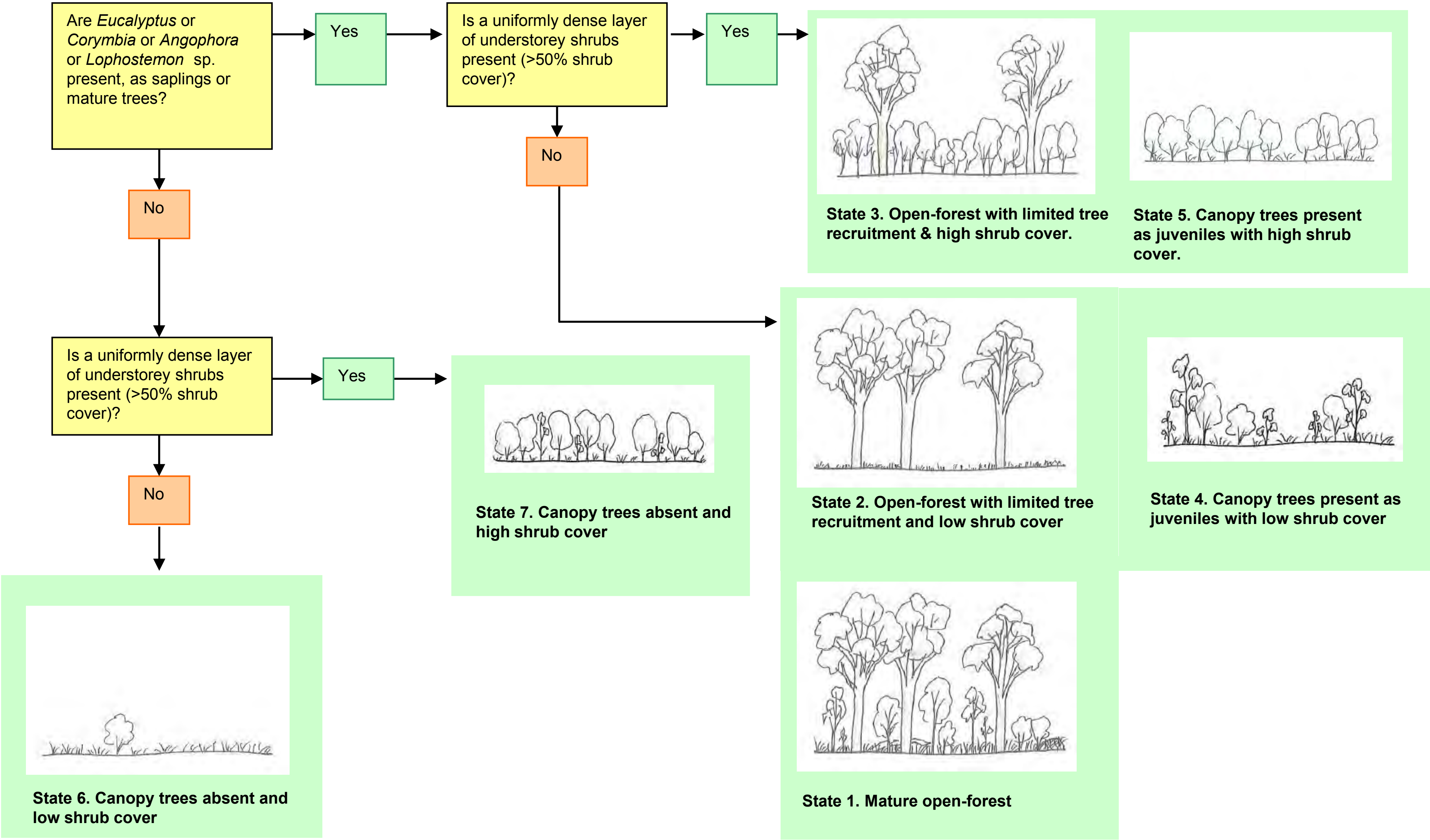


Figure 14:Key to eucalypt open-forest 'states' which feature in the ecological model (Fig. 6)

Table 5: The main management issues for each condition state for eucalypt open-forests; condition states 1,2 & 4, and 3 & 5 have been grouped because their management actions are the same

Condition state	Description	Main management issue
1, 2 & 4	Canopy trees present, low-moderate shrub cover	Areas in these states should require little intervention to sustain or increase their carbon stocks.
3 & 5	Canopy trees present, high shrub cover	High shrub cover may impede the recruitment and replacement of canopy trees.
6	Canopy trees absent, low-moderate shrub cover	Seed sources (and/or tubestock) will be needed to restore canopy trees.
7	Canopy trees absent, high shrub cover	Seed sources (and/or tubestock) and some reduction in shrub cover will be needed to restore canopy trees.

Table 6: Management actions for restoring and maintaining eucalypt open-forests; actions that maximise carbon are indicated by an upwards arrow in the 'carbon' column; those that conserve wildlife are indicated by an upwards arrow in the 'wildlife' column. Ticks indicate which actions are relevant to which condition states. Condition states 1, 2 & 4, and 3 & 5 have been grouped because their management actions are the same.

Action	Benefits	Carbon	Wildlife	Condition state/s			
				1, 2, 4	3, 5	6	7
Clearing and thinning							
1. No broadscale clearing of live trees and shrubs.	• Clearing eucalypt open-forests will reduce the rate of carbon gain, decrease the capacity of the vegetation to store carbon, and produce a net carbon loss. • Careful selective harvesting is compatible with carbon farming, but this will slow the rate of carbon gain, and reduce the amount of carbon stored. • Clearing removes plants and animals, and also removes the food and shelter of animals that depend on trees and shrubs. • Animals which have little or no capacity for dispersal are severely impacted by land clearing.	↑	↑	✓	✓	✓	✓
2. Retain dead standing trees and shrubs, and fallen timber. Minimise or avoid collection for firewood, or 'cleaning-up'.	• Dead trees and fallen timber contribute to the amount of carbon stored. • Dead trees, especially those with hollows, and fallen timber are important shelter and foraging sites for wildlife.	↑	↑	✓	✓	✓	✓
3. Encourage the growth and survival of large trees noting that this may involve thinning.	• Healthy, large trees make a substantial contribution to the amount of carbon stored. • Large trees are more likely to contain and form hollows, provide shelter and foraging sites for wildlife, and they can take a very long time to replace.	↑	↑	✓	✓	✓	✓

Action	Benefits	Carbon	Wildlife	Condition state/s			
				1, 2, 4	3, 5	6	7
Fire							
4. Prevent and suppress moderate to high severity fires.	• Moderate to high severity fires result in net carbon loss by consuming the carbon stored in trees, shrubs, dead wood and litter. • Trees, shrubs, dead wood and litter that would be damaged or destroyed by fire all provide shelter and foraging sites for wildlife.	↑	↑	✓	✓	✓	✓
5. If fuel loads in the under-storey are likely to build up, conduct patchy, low-severity burns, when soil moisture is high, to reduce the risk of moderate to high severity fires.	• Repeated small fires can reduce the rate of carbon gain by removing small trees and shrubs, but small carbon losses are preferable to potentially larger losses from unplanned wildfire. • Reduces the risk of fire in the area to be restored (see **4**).	↑	↑	✓	✓	✓	✓
6. Use grazing management to reduce high fuel loads. This needs to be balanced with allowing the establishment and growth of woody plants (see **10** below).	• Reduces the risk of fire in the area to be restored (see **4**).	↑	↑	✓	✓	✓	✓
7. Use grazing management or low severity burns, when soil moisture is high, to reduce high fuel loads in the surrounding vegetation.	• Reduces the risk of fire in the area to be restored (see **4**).	↑	↑	✓	✓	✓	✓
8. Maintain a range of burning practices that create a fine-scale mosaic of fire histories in the landscape, including unburnt refugia, and to avoid hot fires, especially late in the dry season.	• Native species have diverse responses to fire, so a mosaic of low severity burns that are patchy in space and time should help to conserve the greatest number of species.		↑	✓	✓	✓	✓

Action	Benefits	Carbon	Wildlife	Condition state/s			
				1, 2, 4	3, 5	6	7
9. Rake litter and debris away from the base of large and hollow trees prior to prescribed burning.	• Healthy, large trees make a substantial contribution to the amount of carbon stored. • Helps to protect important habitat trees from scorching, and premature death.	↑	↑	✓	✓		
Grazing							
10. Manage grazing to allow tree recruitment (see next section ***Managing tree density*** for more details)**.**	• Uncontrolled grazing may reduce carbon gain and storage by disturbance to tree and shrub growth and establishment, and by trampling of woody debris and litter. • Uncontrolled grazing by stock, can reduce shelter and food for wildlife by slowing and preventing the recruitment and growth of trees, grasses and understorey shrubs, and by trampling and reducing the amount of litter and fallen timber	↑	↑	✓	✓	✓	✓
11. Control macropods and feral animals (e.g. goats, pigs, rabbits) if they are in sufficient densities to prevent the recruitment of native trees and shrubs (see next section ***Managing tree density*** for more details).	• Uncontrolled grazing may reduce carbon gain and storage by disturbance to tree and shrub growth and establishment, and by trampling of woody debris and litter. • Uncontrolled grazing by feral and native animals can reduce shelter and food for wildlife by slowing and preventing the recruitment and growth of trees, grasses and understorey shrubs, and by trampling and reducing the amount of litter and fallen timber.	↑	↑	✓	✓	✓	✓
12. Establish and maintain an intact pasture/ground layer with appropriate density of perennial ground layer species**.**	• An intact ground layer will reduce erosion and improve water infiltration. This will be beneficial for tree establishment and growth.	↑		✓	✓	✓	✓

Action	Benefits	Carbon	Wildlife	Condition state/s			
				1, 2, 4	3, 5	6	7
13. Establish and maintain an intact ground layer of native plant species, with appropriate density of perennial ground layer species.	• A ground layer of native plant species will reduce erosion and improve water infiltration, and will also help to conserve wildlife.	↑	↑	✓	✓	✓	✓
14. Manage domestic, native and feral herbivores to maintain low to moderate levels of grazing pressure.	• Uncontrolled grazing by domestic, feral and native animals can reduce shelter and food for wildlife by slowing and preventing the recruitment and growth of trees, grasses and understorey shrubs, and by trampling and reducing the amount of litter and fallen timber. • Providing areas of low to moderate grazing pressure will favour many native plant and animal species that find it difficult to survive in highly-grazed landscapes.		↑	✓	✓	✓	✓
Site preparation and plant establishment							
15. Reduce the cover of dense shrubs in areas where canopy tree recruitment is needed. Tree recruitment may be by natural seed sources, direct seeding, or tubestock planting.	• Improves the establishment and growth of woody plants by reducing competition. • This action may have negative effects on wildlife by removing habitat/cover and making the site more suitable for aggressive honeyeaters. To reduce these risks, reduce shrub cover in small areas only, and implement shrub removal in stages, over months or years.	↑			✓		✓
16. Use slashing or low severity fire, when soil moisture is high, to reduce the cover of herbaceous plants before direct seeding or tubestock planting.	• Improves the establishment and growth of woody plants by reducing competition.	↑	↑			✓	✓

Action	Benefits	Carbon	Wildlife	Condition state/s			
				1, 2, 4	3, 5	6	7
17. Revegetate treeless areas with native trees and shrubs using direct seeding or tubestock, when good rains are expected. Try to use seeds and tubestock sourced from local populations of the species that grow on your site. Avoid introducing pathogens to your site by using seed and tubestock that are free of pests and diseases.	• Establishment and growth of woody plants increases the rate and amount of carbon stored. • A diversity of woody plant species of different sizes and ages provides food and habitat for wildlife.	↑	↑			✓	✓
18. Establish a diversity of tree and shrub species.	• A diversity of woody plant species of different sizes and ages provides food and habitat for wildlife.	↑	✓	✓	✓	✓	
Competitors and predators							
19. Avoid management actions that will lead to the development of a uniformly dense shrub layer, e.g. some shrub species will germinate prolifically after fire.	• A uniformly dense shrub layer (> 50 % cover throughout the site) may prevent the recruitment of canopy trees.	↑		✓	✓	✓	✓
20. Control weedy shrubs (e.g. lantana) before they form a dense shrub layer.	• A uniformly dense shrub layer (> 50 % cover throughout the site) may prevent the recruitment of canopy trees. • For more information on lantana control, see http://www.weeds.org.au/WoNS/lantana/	↑	↑	✓	✓	✓	✓
21. Prevent the introduction and spread of serious weeds. Vehicles, quad bikes machinery, and stock can all spread weeds.	• For more information on the management of Weeds of National Significance, see: http://www.weeds.org.au/WoNS/	↑	✓	✓	✓	✓	↑
22. Control weed species where these are having a negative impact on	• Management actions that have adverse effects on wildlife should be avoided if possible, or		↑	✓	✓	✓	✓

Action	Benefits	Carbon	Wildlife	Condition state/s			
				1, 2, 4	3, 5	6	7
wildlife.	implemented in stages.						
23. Control feral animal species where these are having a negative impact on wildlife.	• Pigs, cats, foxes and goats are some of the feral species that may threaten native plants and animals through predation, competition and spreading disease. • Management actions that have adverse effects on wildlife should be avoided if possible, or implemented in stages.		↑	✓	✓	✓	✓
Competitors and predators							
24. Use habitat modification to reduce the numbers of aggressive honeyeaters (noisy miners and yellow-throated miners) where these are having a negative impact on wildlife.	• Miners can have a strong negative influence on the abundance and species richness of other native birds. • Direct control of miners is not recommended. • Increasing the density of stems and understorey shrubs, and reducing grazing pressure, should help to discourage miners, and provide a more suitable habitat for small birds.		↑	✓	✓	✓	✓
Other actions for wildlife							
25. Retain and restore tree and shrub patches of different sizes, ages and stem densities.	• More wildlife species are likely to be supported if a range of vegetation growth types are represented in a given farmland area.		↑	✓	✓	✓	✓
26. Provide nest boxes if hollows are scarce.	• Tree hollows provide important shelter and foraging sites for wildlife. • Hollow-dependent species like bats, birds, insects, and mammals also bring benefits such as pollination and insect control to plantings.		↑	✓	✓	✓	✓
27. Retain and protect large grass tussocks.	• Large perennial grass tussocks provide important shelter and foraging sites for wildlife.		↑	✓	✓	✓	✓

Action	Benefits	Carbon	Wildlife	Condition state/s			
				1, 2, 4	3, 5	6	7
28. Retain and protect mistletoe on eucalypts and other woody plant species.	• Mistletoe provides nectar, berries and nesting sites for many animal species.		↑	✓	✓	✓	✓
29. Retain and protect rocks and rock outcrops.	• Many animals use rocks or rocky areas for shelter, and some plant species may only be found in association with rocky areas.		↑	✓	✓	✓	✓
30. Retain and protect leaf litter including fallen leaves, bark and twigs.	• Many animals use leaf litter for shelter and foraging.		↑	✓	✓	✓	✓
31. Minimise or avoid the use of insecticides in areas to be restored, and prevent spray drift from adjacent areas.	• Invertebrates deserve protection in their own right, but also provide food for other animals, and ecosystem services such as pollination and seed dispersal.		↑	✓	✓	✓	✓
Other considerations							
32. Rainfall will have a large bearing on the success of management actions.	• Extended dry periods may cause the death of mature trees. • Try to revegetate with tubestock or by direct seeding only when good rains are expected.						

Managing tree density

The density of large trees has a large bearing on carbon storage and pasture production. The basic principle for maintaining or increasing tree densities is to make sure there are enough new trees to replace, or augment, the existing canopy trees. But not all 'new' trees are the same, as eucalypts progress through distinct life stages before they develop into mature trees, and each life stage has a different level of tolerance to grazing and fire. This means that the management actions for maintaining or increasing tree density will vary, depending on what types of 'new' trees are present. Whether the landholder wishes to aim for typical large tree densities for the vegetation type (for maximum carbon) or reduced tree densities (for increased pasture production) it is important to understand how to manage different tree life stages to achieve the tree density required.

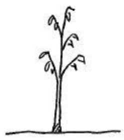
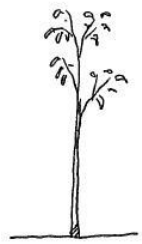
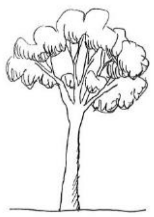
Life stages

For the purposes of this guideline, the three life stages of eucalypts before they develop into mature trees are seedlings, short saplings and tall saplings (Table 8). In this scheme, seedlings are defined by the absence of a lignotuber, and therefore they are usually killed if most shoots are removed by grazing or fire, as they have little capacity to resprout after damage. Once a seedling develops a lignotuber, it has the ability to resprout from the base if its upper shoots are removed. This life stage is termed a 'short sapling'.

In contrast, a 'tall sapling' has grown to a height that puts its upper branches beyond the reach of most livestock, macropods and feral herbivores. Plants in this category have also developed thicker bark on their main stem and larger branches, and the capacity to resprout from upper stems and branches (epicormic resprouting) after damage. This means that tall saplings are more likely to avoid grazing than the previous two life stages, as most herbivores cannot reach all of their branches and leaves.

Both types of saplings often survive low- to moderate-severity fires by resprouting, but the impact on their heights usually differs. The height of short saplings may be reduced as their stems are killed or burnt, and they resprout from their lignotubers, while the height of tall saplings will be less affected as their stems have more protection, and they can resprout from their canopies. Management actions for the recruitment and conservation of different life stages are detailed in Table 7.

Table 7: Life-stage traits for woodland and open-forest eucalypts.

	Life stage	Height (approx.)	Resprouting		Tolerance	
			Lignotuber	Epicormic	Grazing	Fire
	Seedling	Up to ~ 20 cm	no	no	Unlikely to survive if most shoots are removed.	Unlikely to survive fire.
	Short sapling	20 – 150 cm	yes	no	Likely to survive and resprout from base if most shoots are removed.	Likely to survive and resprout from base if most shoots are killed or burnt.
	Tall sapling	> 150 cm[6]	yes	yes	Probably beyond the reach of most herbivores; can resprout from base and upper stems / branches.	Likely to survive and resprout from upper stems / branches and base.
	Mature tree	Canopy height	yes	yes	Probably beyond the reach of most herbivores; can resprout from base and upper stems / branches.	Likely to survive and resprout from upper stems / branches and base.

Tree density

Tree density can be **increased** by encouraging the establishment and growth of seedlings and/or saplings, so that the recruitment rate of new trees into the canopy is greater than the mortality rate of mature trees if present. The exact number of seedlings and saplings needed to produce a mature tree is difficult to define, as many factors will influence the survival and growth of seedlings and saplings such as rainfall, fire, grazing, and so forth.

[6] Based on the development of epicormic resprouting in *C. clarksoniana* when it is over 150 cm in height (P. Williams *pers. comm.*).

A rough estimate of replacement ratios is:

30 seedlings are likely to provide →

10 short saplingswhich are likely to provide →

5 tall saplingswhich are likely to provide→ **One mature tree**

These replacement ratios are based on ideal growing conditions, and the appropriate management of grazing and fire for the different life stages.

Table 8: Management actions for the recruitment and conservation of different tree life stages. These actions are in addition to the general management actions for condition states in Table 7.

Life Stage	Management Actions
Seedlings	• Seedling establishment will be more successful when periods of unusually high rainfall coincide with, and continue after, seeds are released. • If using manual or machine seeding to establish seedlings, try to do this when a period of unusually high rainfall is expected. • Reducing the amount of herbage and shrub cover before seed drop (by mechanical clearing, grazing, or low-severity fire) may also assist seedling establishment. • Exclude livestock and exclude or control other herbivores until seedlings develop into short saplings. • Protect from fire.
Short saplings	• This life stage is still within the reach of most herbivores, so grazing pressure may need management until short saplings develop into tall saplings.
Tall saplings	• Reduce stocking rates and/or control or exclude native and feral herbivores if grazing is damaging saplings.

To **maintain** tree density, the mortality rate of mature trees should be equal to the recruitment rate of new trees into the canopy. The time between tree death and replacement can be minimised by conserving a ‘bank’ of tall saplings scattered throughout the site. When a mature tree dies, it is likely that nearby saplings will grow to replace it. Once again, the number of tall saplings needed to replace a mature tree will depend on many factors, but five saplings per mature tree may be the minimum required.

If there are no tall saplings present, it is likely that larger numbers of short saplings and seedlings will be required to replace a mature tree, given the generally higher mortality rate of these earlier tree life stages. The replacement ratios provided above can be used as a rough guide for maintaining tree density in mature eucalypt open-forests.

The growth rate of eucalypts, higher rates of mortality during droughts, and the impacts of dieback and insect pests should all be considered when managing tree densities and preparing for tree replacement. A larger ‘bank’ of saplings and small trees may reduce pasture production but is more likely to enable the rapid replacement of large trees, and the maintenance of maximum carbon levels.

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